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An 8.4-GHz Cryogenically Cooled HEMT Amplifier for DSS 13

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A prototype 8.4-GHz (X-band) high electron mobility transistor (HEMT) amplifier/closed-cycle refrigerator (CCR) system was installed in the DSS 13 feedcone in August 1987. The amplifier is cryogenically cooled to a physical temperature of 12 K and provides 31-K antenna system noise temperature (zenith) and 35 dB of gain at a frequency of 8.2 to 8.6 GHz. Antenna system noise temperature is less than 50 K from 7.2 to 9.4 MHz. The low-noise HEMT amplifier system is intended for use as a radio astronomy or space communications receiver front end.

I. Introduction

This article describes the design, assembly, and performance of the first 8.4-GHz high electron mobility transistor (HEMT) amplifier system designed for the DSN. This system was installed on the DSS 13 antenna at Goldstone, California, in August 1987, where it is mounted beside the 2.3-GHz HEMT/CCR amplifier system [1]. A performance goal for this system was to provide the widest possible operating bandwidth for radio science applications while maintaining state-of-the-art noise performance in the DSN 8.2- to 8.7-GHz band. The antenna system noise temperature (looking at zenith, clear weather) measures less than 50 K across an instantaneous bandwidth of 7.2 to 9.4 GHz with the use of this HEMT/CCR system. At midband, antenna system noise is as low as 31 K. At the room temperature waveguide input flange at a frequency of 8.42 GHz, the amplifier input noise temperature measures 13 K. The operating frequency range of the HEMT/CCR system includes frequencies that operate very close to the DSS 13 transmitter frequency, and since no cryogenic transmitter reject filter has been provided, system operation is limited to

a listen-only mode.¹ The narrower-bandwidth 8.4-GHz traveling wave maser system remains available for use when diplexed operation is desired (see Fig. 1).

II. General Description

Figure 1 is a block diagram of the signal distribution for the DSS 13 8.4-GHz microwave front end, including the 8.4-GHz HEMT/CCR system. Figure 2 is a photograph of the HEMT/CCR package with vacuum housing and radiation shield removed to show the components mounted on the 12-K refrigerator station. The 12-K closed-cycle refrigerator contains a cryogenically cooled waveguide input transmission line,

¹This amplifier design typically experiences 1 dB of gain compression at -25 dBm input CW power. If diplexed operation is desired, a cryogenic filter (or, alternatively, an external waveguide filter) must be provided to attenuate transmitter leakage from the diplexer receiver port (up to +20 dBm in 1985) to a level that is at least 10 dB below that which causes 1-dB saturation (approximately -35 dBm).

a cryogenic input isolator, a three-stage amplifier that contains a HEMT in the first stage and GaAs FET devices in the second and third stages, and a cryogenic output isolator. Figure 3 shows the completed HEMT/CCR package.

III. Detailed Description

A. Cryogenic Input Transmission Line

The function of the input transmission line is to transmit the input RF signal from the room temperature WR 125 waveguide flange to the cryogenic low-noise amplifier while adding the least possible noise and an acceptably low heat load to the CCR system. A mica waveguide window on the top supports a vacuum in the CCR dewar. A thermal barrier separating the 300-K and 12-K portions of the input waveguide is achieved by a 0.005-inch gap in the waveguide wall. A radial choke prevents RF leakage from the gap. A waveguide-to-coaxial transition couples the input signal to a semi-rigid coaxial line at a 12-K physical temperature. The noise contribution of this assembly is estimated to be less than 0.5 K based on room temperature insertion loss measurements.

B. Cryogenic Isolator

A cryogenically cooled isolator is included at the input of the HEMT amplifier to provide good input match over the entire bandwidth. The cryogenic isolator, P&H Laboratories Model C1-X-13366, has a return loss exceeding 18.5 dB from 8.2 to 8.7 GHz and an insertion loss of 0.13 dB. The estimated noise contribution of this assembly is approximately 1 K or less.

C. HEMT Amplifier Module

The HEMT/FET/FET amplifier module is shown in Fig. 4. The amplifier is a three-stage microstrip circuit design now commercially available from Berkshire Technologies, Inc. The first-stage HEMT is a commercially available 0.5- μ m device, the Fujitsu FHR01FH. The second-stage and third-stage FETs are the Mitsubishi 1412 and 1402, respectively. Each stage is individually biased for optimum low-noise performance. Low-temperature HEMT performance is often complicated by a sensitivity to light, which is thought to be associated with the existence of traps in the AlGaAs layers [2], [3]. Minimum noise temperature is achieved with the Fujitsu HEMT device by application of a low level of light. An LED mounted in the cover of the amplifier provides this function. An output isolator is included to ensure >15 dB of output return loss. The minimum input noise temperature (at 8450 MHz) of the completed three-stage amplifier is 13 K with 35 dB of gain (includes the input and output isolators). It should be noted that the Fujitsu FHR01FH HEMT used in this amplifier is a very early device; the more recent shipments of this HEMT have not provided state-of-the-art noise performance.

D. Closed-Cycle Refrigerator

The HEMT/CCR package uses a Cryogenics Technology, Inc., Model 350 Cryodyne refrigerator and compressor. This is the same CCR used for all cryogenic FET and HEMT amplifiers in the DSN. The refrigerator is enclosed in a vacuum housing and radiation shield designed specifically for DSN applications. The first stage of the refrigerator operates at approximately 50 K and the second stage at 12 K. The refrigerator is designed to provide an unloaded cooling capacity of 15 watts at 70 K and 3 watts at 15 K. Cool-down time of the HEMT/CCR system is approximately 5 hours. The fully loaded reserve heat capacity was measured to be 2.7 watts at the 15-K second-stage station. The completed HEMT/CCR package is shown in Fig. 3.

IV. DSS 13 Installation and Performance Tests

Prior to installation, the input noise temperature of the assembled HEMT/CCR package was measured at JPL using the Y-factor method. A horn was attached to the amplifier input and Y-factors were obtained by switching between "cold sky" and a room temperature aperture load. The input noise temperature at the room temperature waveguide flange measured 13.0 to 13.2 K across the 8400- to 8500-MHz range. On July 10, 1987, the HEMT/CCR was installed at DSS 13, and antenna system noise temperature was subsequently measured at zenith during clear weather. These results are shown in Fig. 5.

Since the HEMT/CCR system replaced a maser/CCR system, it is appropriate to compare the characteristics of these two types of low-noise amplifier systems:

- (1) The HEMT amplifier provides excellent noise performance in a 12-K cryogenic refrigerator, whereas the maser requires a more complex and less reliable 4.6-K refrigerator.
- (2) In the event of a refrigerator and/or compressor failure, the noise temperature of a HEMT/CCR system degrades in a gradual "fail-soft" manner. Figure 6 shows the input noise temperature of the DSS 13 8.4-GHz HEMT/CCR as a function of time after the refrigerator and the compressor were turned off. Noise temperature, normally 13 K, degraded to 20 K after 45 minutes and reached approximately 25 K in 2 hours.
- (3) HEMT systems provide greater bandwidths than do maser systems. Masers, on the other hand, provide the lowest possible noise temperatures when ultimate noise performance is required, such as for Voyager and other spacecraft downlink applications.

- (4) HEMT amplifiers have no tuning controls that need to be adjusted in the field. Masers require tuning of the magnet and pump source (oscillators).
- (5) HEMT/CCR systems are smaller, less complex, and lighter in weight than maser systems.
- (6) HEMT amplifiers experience gain compression at approximately -25 dBm compared to -85 dBm for masers.
- (7) The HEMT amplifier will be permanently damaged when input power exceeds 100 to 500 mW, while a maser can survive many watts of input power (a distinct advantage during those few occasions when transmitter power has been accidentally applied to a maser-receiver system configured for listen-only).
- (8) The reliability of the DSS 13 X-band HEMT/CCR has not been as good as that of other FET/CCR systems because of a small vacuum leak that has not been considered serious enough to repair. This vacuum leak makes it necessary that the system be warmed and pumped down with a vacuum pump during a convenient time period approximately every 3 months. Otherwise, during the 14 months since installation, only one

failure occurred: a chip capacitor delaminated in the HEMT module. Berkshire Industries identified this capacitor as one that has failed in many of their commercial cryogenic amplifiers. A different capacitor was installed that has proven to be reliable in cryogenic use.

V. Conclusions

Since the time of installation, there have been numerous VLBI and other radio astronomy experiments utilizing the HEMT amplifier. The amplifier has proven to require less operator attention than have previous maser systems, and repairs are typically less time-consuming. The gain stability of this system, as well as that of the complete DSS 13 receiver subsystem, is very good. A 50-mK radio spectrum has been resolved with a noise level of 10 mK for a 45-minute integration time (T. Kuiper, private communication).

Since installation of this system, lower-noise HEMT devices have been developed by the General Electric Company. It is expected that the amplifier noise temperature of this system (at the room temperature waveguide input flange) could be reduced to less than 10 K at 8.2 to 8.7 GHz with the use of one of these GE devices.

Acknowledgments

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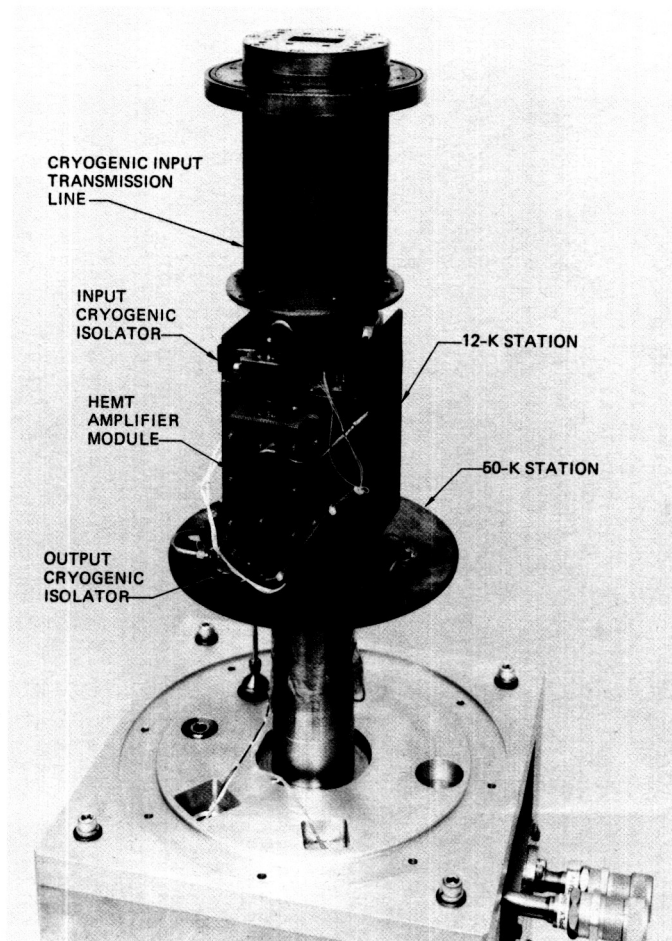


Fig. 2. HEMT/CCR package with vacuum housing removed

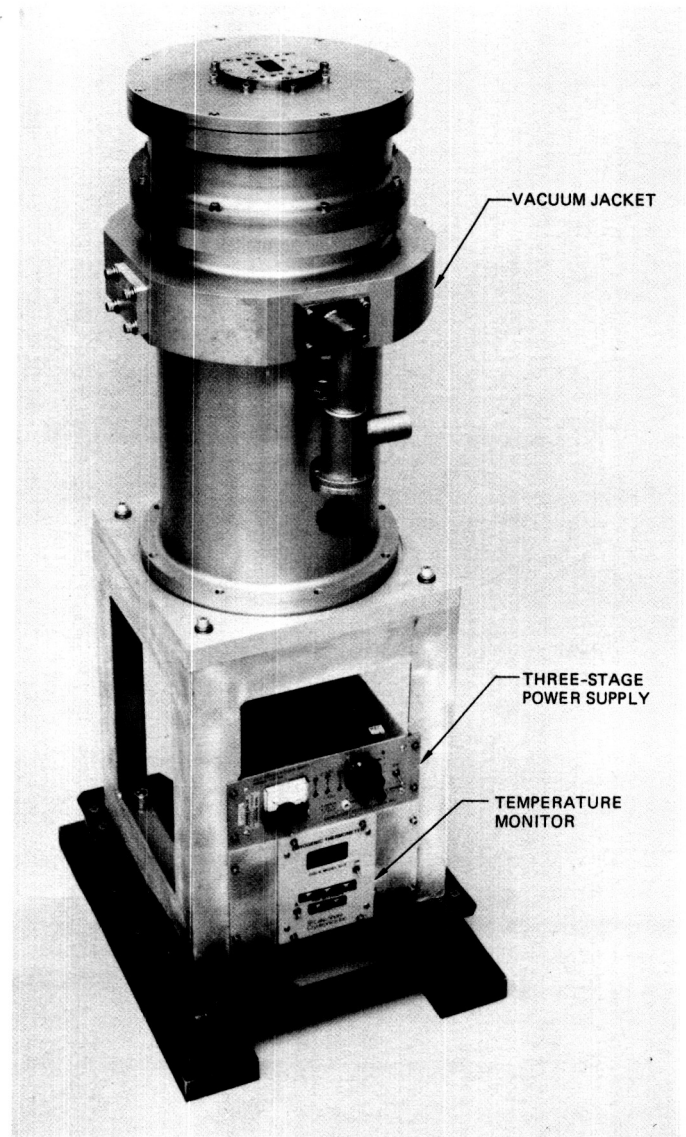


Fig. 3. HEMT/CCR assembly

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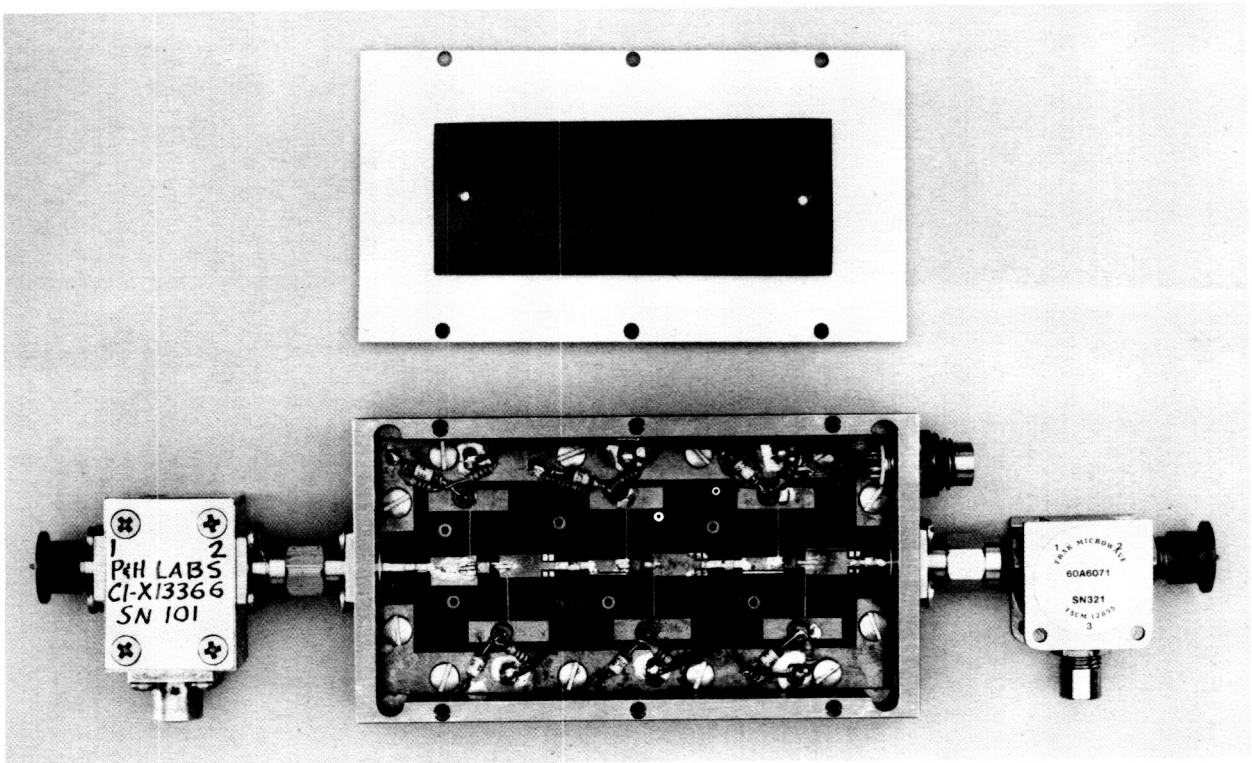


Fig. 4. Three-stage HEMT/FET/FET amplifier module

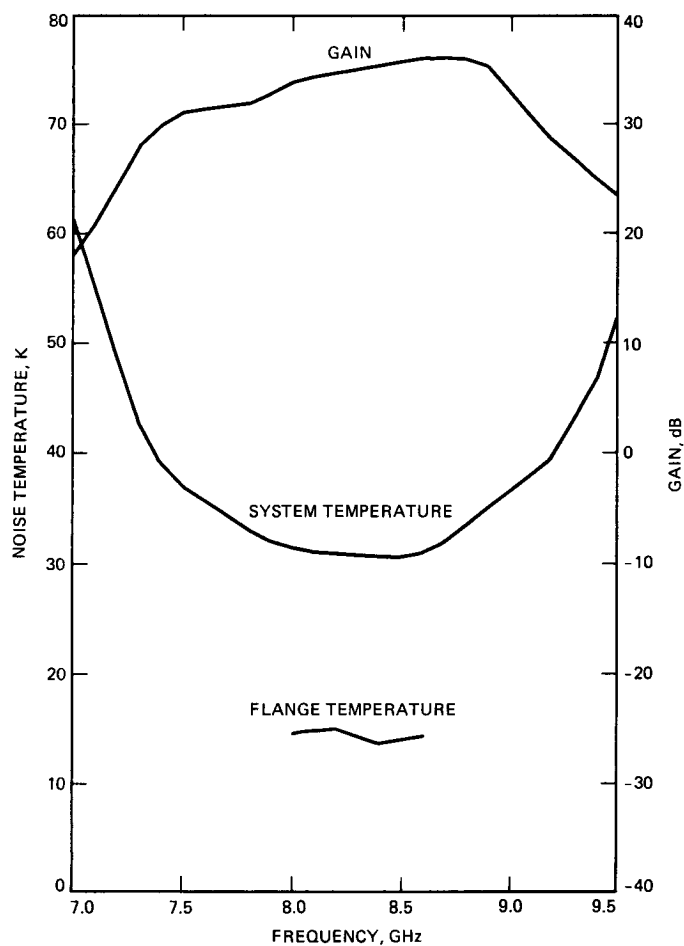


Fig. 5. System temperature, flange temperature, and gain measurements

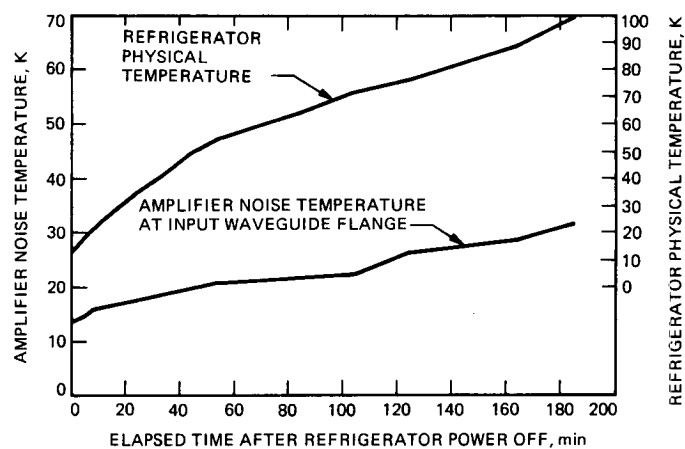


Fig. 6. Input noise temperature and refrigerator physical temperature as a function of refrigerator warmup